APPLICATION FOR UNITED STATES PATENT

in the name of

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Of

Align Technology, Inc.

For

Treatment Analysis Systems and Methods

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Treatment Analysis Systems and Methods

BACKGROUND

The invention relates generally to the field of orthodontics and, more particularly, to computer-automated orthodontic treatment of teeth.

Tooth positioners for finishing orthodontic treatment are described by Kesling in the *Am. J. Orthod. Oral. Surg. 31*:297-304 (1945) and *32*:285-293 (1946). The use of silicone positioners for the comprehensive orthodontic realignment of a patient's teeth is described in Warunek et al. (1989) *J. Clin. Orthod. 23*:694-700. Clear plastic retainers for finishing and maintaining tooth positions are commercially available from Raintree Essix, Inc., New Orleans, Louisiana 70125, and Tru-Tain Plastics, Rochester, Minnesota 55902. The manufacture of orthodontic positioners is described in U.S. Patent Nos. 5,186,623; 5,059,118; 5,055,039; 5,035,613; 4,856,991; 4,798,534; and 4,755,139. Other publications describing the fabrication and use of dental positioners include Kleemann and Janssen (1996) *J. Clin. Orthodon. 30*:673-680; Cureton (1996) *J. Clin. Orthodon. 30*:390-395; Chiappone (1980) *J. Clin. Orthodon. 14*:121-133; Shilliday (1971) *Am. J. Orthodontics 59*:596-599; Wells (1970) *Am. J. Orthodontics 58*:351-366; and Cottingham (1969) *Am. J. Orthodontics 55*:23-31. Kuroda et al. (1996) *Am. J. Orthodontics 110*:365-369 describes a method for laser scanning a plaster dental cast to produce a digital image of the cast. See also U.S. Patent No. 5,605,459.

U.S. Patent Nos. 5,533,895; 5,474,448; 5,454,717; 5,447,432; 5,431,562; 5,395,238; 5,368,478; and 5,139,419, assigned to Ormco Corporation, describe methods for manipulating digital images of teeth for designing orthodontic appliances.

U.S. Patent No. 5,011,405 describes a method for digitally imaging a tooth and determining optimum bracket positioning for orthodontic treatment. Laser scanning of a molded tooth to produce a three-dimensional model is described in U.S. Patent No. 5,338,198. U.S. Patent NO. 5,452,219 describes a method for laser scanning a tooth model and milling a tooth mold. Digital computer manipulation of tooth contours is described in U.S. Patent Nos. 5,607,305 and 5,587,912. Computerized digital imaging of the jaw is described in U.S. Patent Nos. 5,342,202 and 5,340,309. Other patents of interest include U.S. Patent Nos. 5,549,476; 5,382,164; 5,273,429; 4,936,862; 3,860,803; 3,660,900; 5,645,421; 5,055,039; 4,798,534; 4,856,991; 5,035,613; 5,059,118; 5,186,623; and 4,755,139.

U.S. Patent No. 5,975,893, assigned to the assignee of the instant invention, describes a system for repositioning teeth using a plurality of individual appliances. The appliances are configured to be placed successively on the patient's teeth and to incrementally reposition the teeth from an initial tooth arrangement, through a plurality of intermediate tooth arrangements, and to a final tooth arrangement. The system of appliances is usually configured at the outset of treatment so that the patient may progress through treatment without the need to have the treating professional perform each successive step in the procedure.

SUMMARY

A dental treatment planning system includes an input form to receive one or more dental patient inputs; and an engine adapted to receive the dental patient data from the input form and validating the dental patient data in a predetermined sequence.

Implementations of the system may include one or more of the following. The engine prompts the user for additional data based on previous entries. The treatment includes a diagnostic phase, a goal phase and a treatment path determination phase. The engine checks validity for data entered intra-phase. The validity of the entries is determined by crosschecking against a mutually exclusive condition. The engine checks validity for data entered inter-phase. The engine checks whether the treatment results in an improvement in the patient. The engine checks whether the treatment meets an efficiency guideline or a prudency guideline. The engine can also check the treatment plan against properties of an appliance.

Advantages of the system include one or more of the following. The system improves the accuracy and validity of diagnoses and treatment plan by providing the orthodontist with information and resources to make the measurements that will result in the correct diagnosis.

The system also prevents an orthodontist from entering conflicting diagnoses. Because a patient's teeth and the way they define a bite are interrelated, a series of logical rules are used to crosscheck the diagnoses and to prevent an invalid diagnosis. The system also checks for and requires the entry of a diagnosis for any area for which one is required. This prevents one type of inaccuracy in diagnosis, in that a negative finding is equivalent to an incorrect positive finding.

The system also limits path choices based on the initial and end points for teeth. This prevents an inaccurate path by limiting the path choices to those that head in the correct direction. The system also prevents for the orthodontist from entering two conflicting paths. By cross checking the paths, the system can eliminate invalid paths.

Additionally, certain shortcomings of the appliances with regard to the biology, physics, and mechanics of tooth movement are known. Thus, the system considers the biology, physics, and material of tooth movement in optimizing the treatment plan. The system prevents the orthodontist from entering a goal that is not deemed attainable by the system and the information can be relayed to the doctor when a valid and accurate plan is described that involves these shortcomings. This will allow the doctor to tailor the plan to avoid any pitfalls inherent in the system. Moreover, the system provides feedback, for example direction and education, when the orthodontist is prevented from entering data not allowed by the system. Because there are multiple goals and paths to reach them, a quality result is not guaranteed from an accurate and valid diagnosis. Feedback when a mistake is made in the diagnosis can be used to educate and direct the thinking of the doctor which will perhaps lead to the redevelopment of an entirely new, better, plan, rather than the mere correction of the error which generated the feedback.

In implementations that permit communications over the Internet, the system provides information and assistance 24 hours a day, seven days a week. The system supports a virtual community of dental patients, dentists, specialists such as orthodontists and oral surgeons, financial institutions, benefit providers and the providers of dental equipment or services. For treating professionals, such as dentists and orthodontists, the system provides a one-stop solution for planning patient treatments, managing communication with patients, storing patient records and sharing records with relevant persons outside the doctor's office. The system can act as the repository for the file notes and visual imagery (photographs, x-rays and virtual treatment plans) associated with the course of treatment. The doctors will control access to the centralized patient file.

Various tools are provided to support the interpretation of information and the diagnostic process. For example, the system allows the doctors to retrieve, and analyze patient information and to simulate using two and three-dimensional visual imagery of the patient's teeth and other anatomical structures. The system supports visualization of the expected outcome of a particular course of treatment. Working together with the patient these images can enhance the patient's understanding of the benefits of treatment and act as a valuable selling tool for the doctor. The system also provides diagnostic decision-support capabilities such as visualizing the placement of implantations, veneers and crowns before or after a course of treatment to straighten the teeth. The system provides an animated prediction of the suggested treatment that helps the patient and the doctor to visualize the pace of treatment. Using these tools, the doctor can easily and quickly view and/or edit the treatment plan. When doctor and patient choose the final treatment plan the system disseminates aspects of the plan and the relevant patient records to the appropriate members of the virtual community, thus reducing the cost and delay associated with tradition physical shipment of patient information. Aspects of the final treatment plan can be used to generate appliances used in the physical treatment. The information associated with the patient's treatment (visual images, virtual treatment plans, file notes and the like) are digitized and maintained in a central storage facility in a secure manner. Doctors and patients can have access to these files without the need to extract files and models from storage and with reduced risk of records being misplaced.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of an exemplary environment supporting electronic commerce.

Fig. 2 is a diagram of a server to support electronic commerce.

Fig. 3 is a diagram of a web site on the server of Fig. 2.

Fig. 4 is a flowchart of a process for a patient receiving dental treatment.

Fig. 5 is a flowchart of a process for a treating a dental patient.

Fig. 6 is an exemplary output showing a treatment plan form and a 3D view of teeth with a browser.

Fig. 7 is a flowchart of a process to diagnose and generate a patient treatment plan.

Fig. 8 is one exemplary implementation of Fig. 7.

Fig. 9 is a diagram of a system for manufacturing appliances.

Fig. 10 is a diagram illustrating a computer system to support the fabrication of appliances.

DESCRIPTION

Referring now to Fig. 1, an environment supporting a dental system 100 is shown. The system 100 communicates over a network 102 that can be a local area network or a wide area network such as the Internet. The Internet has become a significant medium for communication and commerce and has enabled millions of people to share information and conduct business electronically. The unique characteristics of the Internet such as its ability to provide enhanced communication, rich text, and graphic environment provide an ideal support for a wide variety of electronic commerce transactions. The ubiquity and convenience of the Internet makes it ideal for dispensing information on certain topics that traditionally require visits to specialists. For example,

certain consumers may be interested in products and services associated with orthodontics and dentofacial orthopedics that specializes in the diagnosis, prevention and treatment of dental and facial irregularities ("malocclusion" or "bad bite"). The orthodontic treatment process typically uses corrective appliances such as braces and/or other fixed or removable appliances to bring the teeth, lips and jaws into proper alignment and to achieve a facial balance. The pervasiveness of the Internet makes it an ideal source for information relating to these products and services.

One or more client computers 104-105 can be connected to the network 102. In one embodiment where the network 102 is the Internet, the client computers execute a suitable browser such as Navigator from Netscape, Inc. and Internet Explorer from Microsoft Corp. By clicking on the highlighted text (or specific graphic image), the user can jump from the current web page to a new web page address associated with the link--with the new page displayed on the screen. In this manner, the user can "surf the web" by clicking on an almost endless succession of links going to page after page all following a common thread as defined by the text or graphic component of the link label.

Through the network 102, the client computers 104-105 can access a dental server 106. The dental server 106 serves a web site, a portal, a vortal, or a content site for providing dental related information to interested parties such as dental patients, dentists, orthodontists, and others. When sensitive information is communicated through the dental server 106, such information is securely encrypted using Secure Sockets Layer (SSL) technology throughout the transaction. The server 106 can be a stand-alone computer or can be a server farm that can distribute processing and communications activity across a computer network so that no single device is overwhelmed. During load

balancing, if one server is swamped with requests, excess requests are forwarded to another server with more capacity.

The network 102 connects the dental server 106 to one or more treating professional workstations 108-109. The workstations 108-109 allow treating professionals access to a plethora of services provided by the dental server 106 such as patient treatment and office management, among others. The dental server 106 stores information associated with patient history on-line in a secure manner. The server 106 also allows the treating professional to have a comprehensive view of the patient's treatment history at any time using a suitable browser, eliminating the need to pull treatment files or charts or to look for misfiled or lost charts. The dental server 106 also provides treating professionals with tools to analyze patient data, for example, tools to reconstruct a 3D model of the teeth. For example, using the browser, the treating professional can request the server 106 to animate the progress of the treatment plan. When the treating professional arrives at a prescription or other final designation, the treatment prescription is used to automatically generate appliances, as described in more details below. Further, in addition to aiding professionals in treating patients, the treating professional can perform office management, purchasing and other logistical operations using the browser and the dental server 106.

In addition to communicating with patients and treating professionals, the dental server 106 can communicate with one or more partners 110 using the network 102. The partners 110 can be product suppliers, service providers, or any suitable commercial entities. Other possible partners include value-added service providers such as third party

software providers who provide plug-in viewing and diagnostic enhancements that can be used by the professionals.

In combination, the dental server 106 forms a hub that links dental clients using client computers 104-105, treating professionals using workstations 108-109, and partners 110 into a living electronic commerce (e-commerce) community.

Fig. 2 shows an embodiment of the server 106. The server 106 includes a web server 140, a patient information server 142, a resource planning (RP) server 144 and a streaming server 146. In one embodiment, the RP server 144 runs Microsoft SQL server and provides information relating to a doctor or a patient such as address and history. When a patient's case or static snapshots of the case is needed, the data is pulled from the patient information server 142. When media data such as video needs to be streamed to a requesting client, the streaming server 146 can send the stream. In one implementation, the streaming data is stored in QuickTime format on a Linux-based server running the QuickTime server software.

The servers can be clustered. In one embodiment using Microsoft's Cluster Server, cluster-enabled applications such as Microsoft's SQL Server and Exchange. With Cluster Server, two servers can run applications at the same time. When one server fails, the remaining server handles its application as well as the failed server's applications. Next, the remaining server adopts the IP address of the failed server and mounts one or more data drives that the two systems share. The remaining server is rebooted and applications such as SQL Server can be started and initialized on this server. Persistent clients can re-attach to the server and continue to operate.

Referring now to Fig. 3, a diagram 200 shows various major functions supported by the dental server 106. First, the process 200 performs an automatic detection for the existence of a browser welcome plug-in (step 202). If the welcome plug-in exists, an introductory animation (flash) is shown (step 204). From step 202 or 204, the process 200 shows a home page (step 206) with one or more links. A link is created by having a word in a text field (or a graphic image on a web page) linked to the location of another web page, via a string of information setting forth the new web page address presented in hypertext transfer protocol (HTTP), among others.

The user can navigate the home page to join a particular site from a constellation of related sites. For instance, the user can navigate to a patient's site (step 208), a doctor's site (step 210), a privacy statement site (step 212), one or more additional sites (step 214), and an about site (step 216), among others. The additional sites can be an on-line shopping store that is co-branded with the web site hosted by the server 106, or the on-line shopping store can be directly affiliated with a third party such as planet-rx.com, among others. The additional sites can also be third party value-added providers of products and/or services.

Fig. 4 illustrates an exemplary usage of the system of Fig. 1 from a treating professional's perspective. A prospective patient uses a client computer 104 and visits the web site on the dental server 106 (step 280). The client identifies a treating professional and schedules an appointment with the treating professional. Alternatively, a referring dentist can refer the client to the treating orthodontist (step 282). The referring dentist can visit the web site on the dental server 106 and uses one or more dental esthetic

tools to show patients the potential benefits of anterior and posterior esthetic restorations and, if the patient is interested, refers the patient to the treating professional.

During an initial examination, the treating professional or an assistant takes a set of digital facial and intraoral images which is uploaded to a secure, collaborative workspace on the dental server 106 (step 284). The workspace is shared with the referring dentist.

Next, the treating professional generates a dentofacial treatment visualization showing the patient's face and smile before and after treatment (step 286). The treating professional can also combine the patient's face and an aligner into the intraoral image to show how the inconspicuous the appliance will be (step 288).

Once the patient requests treatment, the treating professional takes impressions and a bite registration and sends the information to the company (step 290). The treating professional also takes a lateral ceph and a panorex and uploads them and a treating prescription to the workspace (step 292). The professional's assistant creates a separate workspace for the patient, uploads selected "before and after" images into it, and invites the patient to review the images (step 294).

At the company, another professional reviews the records and decides to accept or decline the case (step 296). The models are then scanned, and the intraoral images are retrieved and used to texture-map enamel and gingiva (step 298). The data is then sent to the workspace and the treating professional is notified (step 300).

In one embodiment, the tooth models may be posted on a hypertext transfer protocol (http) web site for limited access by the corresponding patients and treating clinicians. Since realistic models have a large volume of data, the storage and

transmission of the models can be expensive and time consuming. To reduce transmission problems arising from the large size of the 3D model, in one embodiment, data associated with the model is compressed. The compression is done by modeling the teeth meshes as a curve network before transmission to the treating professional. Once the curve network is received, the 3D model is reconstructed from the curve network for the treating professional to analyze. More information on the compression is disclosed in a co-pending application having Serial No. 09/506,419, entitled, "EFFICIENT DATA REPRESENTATION OF TEETH MODEL", and filed by ELENA PAVLOVSKAIA and HUAFENG WEN on February 17, 2000, the contents of which are hereby incorporated.

The treating professional can, at his or her convenience, check the setup, and review the information sent in step 300 (step 302). The treating professionals can use a variety of tools to interpret patient information. For example, the treating professional can retrieve and analyze patient information through a reconstructed 3D model of the patient's teeth and other anatomical structures. The professional can view animations showing the progress of the treatment plan to help the treating physician visualize the pace of treatment. Using these tools, the treating professional can easily and quickly view and/or edit the treatment plan.

If necessary, the treating professional can adjust one or more teeth positions at various intermediate stages of treatment (step 302). A variety of diagnostic decision-support capabilities such as automated teeth collision detection can be used to aid the treating professional in adjusting the teeth positions.

When the treating professional arrives at a prescription or other final designation, the treatment information is automatically collected by the system over the Internet, thus

eliminating the cost and delay associated with the traditional physical shipping of patient information (step 304). These modifications are then retrofitted onto the dataset used to generate the aligners (step 306).

In order for the orthodontist to treat a case, the orthodontist needs to generate a treatment plan, typically after performing an initial diagnosis. A correct initial diagnosis is needed for certain orthodontic appliances such as the Invisalign appliances from Align Technology, Inc. of Sunnyvale, California. To optimally use the Invisalign treatment, the orthodontist needs to accurately define the course of treatment at time zero. The interrelationship of all of the teeth to form a particular bite allows the initial diagnoses to be checked against each other for validity. However, the entire set of diagnoses can be inaccurate together, and would not be caught by such a crosscheck.

Fig. 5 shows a process for treating teeth. First, a treating professional such as an orthodontist or a doctor logs on to a treatment planning system (step 350). Next, a diagnosis portion of the treatment planning system is displayed (step 352). Also, the system displays a 3D view of the patient's teeth (step 354). In this case, a static bite 0 image is displayed. The bite 0 image refers to the position the teeth are in at time zero, or the pretreatment state. The rendering of the 3D view of the teeth focuses the doctor on problems that need to be addressed. The teeth displayed on the screen are the actual teeth and bite that will be used to generate the treatment. Because of this, the doctor is able to accurately plan the treatment by using this view of the teeth, as opposed to previously taken photos of the teeth. An exemplary user interface at step 354 is shown as Fig. 6. This window of the teeth shows a 3D rendering of the patient's teeth, which can be moved in all three planes of space to gain a better view. The window can also be

opened to show further visual diagnostic data such as patient X-rays, photos, or any other data useful for the diagnostic process.

Referring back to Fig. 5, the system prompts the doctor to fill-out the diagnostic portion of the form (step 356). The diagnostic portion of the form requires that the doctor input data relating to the teeth which are present, their condition, their position in the dental arches, their relationship to each other, their size, and their alignment. Once the diagnostic portion of the form has been entered, the system performs a validity check of the diagnostic entry (step 358). The entered data can be crosschecked against Align Technology's case selection criteria to ensure that the submitted case is acceptable for treatment.

The system then displays a treatment goal portion of the form and requests the doctor to fill this portion of the form (step 360). The system then performs a validity check of the treatment goal entry (step 362). Because of the fact that the teeth are all related to each other by virtue of their position, it is possible to cross check the entered treatment goal data against itself, as well as against the previously entered diagnostic data. Additionally, it allows a cross check against Align Technology's case selection criteria for what is possible with the system. Thirdly, the answers from each question prompt specific subsequent questions. For example, when a treatment goal input is given, the system checks that the input is compatible with previous diagnostic input, that the treatment goal is realistic with what Align Technology deems acceptable, and that the treatment goal is compatible with other previously entered treatment goals. The data that has been input will generate further questions, and eliminate possible questions that do not have to do with that particular patient.

The system then displays a treatment plan portion of the form and requests the doctor to fill this portion of the form (step 364). The form now knows the start point of all the teeth (from the diagnostic portion) and the end point (from the treatment goal portion). Specific questions are generated to guide the doctor through a plan for how to get the teeth from their start to end position. The system then performs a validity check of the treatment plan entry (step 366). This validity check ensures that the doctor does not enter two incompatible answers that would involve the teeth running into each other, or not heading in the direction of the goal, etc.

Additionally, the system generates a summary of the treatment plan (step 368). The summary consists of all of the input of the treatment planning form. It is designed for review by the doctor to allow the doctor to review all of the entered data and ensure that it is in accordance with what he intended.

Fig. 7 shows various phases associated with a treatment plan. First, the system captures data relating to a diagnostic phase (step 370). The system performs validity check on the received data before proceeding to the next phase.

After validating diagnostic phase data, the system then captures data relating to a diagnostic phase (step 372). The system performs validity check on the received data for the current phase (intra-phase) as well as checking for proper relationships between phases (inter-phase) before proceeding to the next phase.

After validating goal phase data and checking for proper relationship between the diagnostic phase and the goal phase, the system then captures data relating to a treatment path phase (step 374). Again, the system performs validity check on the received data for

the current phase (intra-phase) as well as checking for proper relationships between phases (inter-phase) before generating the treatment plan.

Fig. 8 shows an embodiment of the flowchart of Fig. 7. First, the process of Fig. 8 receives diagnostic data (step 380). Next, the process checks whether the data is valid (step 382). If not, the process loops back to step 380 to validate data for the diagnostic phase.

From step 382, if the data is valid, the process receives treatment goal input data (step 384). Next, the process checks for valid data (step 386). If the data is invalid, the process loops back to step 384 to collect and validate the goal input data.

From step 386, if the data is valid, the process also checks that the treatment goal improves the patient's condition (step 388). If the treatment goal fails to improve the patient, the process loops back to step 384 to prompt the user to update the treatment goal and to validate the treatment goal once more.

From step 388, the process of Fig. 8 receives treatment plan path input data from the user (step 390). Next, the process validates the treatment plan path data (step 392). From step 392, the process also checks to ensure that the proposed path results in a treatment that is efficient and that follows a desired order (step 394). If the path is undesirable, the process of Fig. 8 loops back to step 390 to receive updated treatment plan path data. Alternatively, if the path is acceptable, the process exits.

As an example, a doctor may enter, among other things, the following information: Diagnosis; Right Canine Sagittal relationship: End on Class II (This describes the relationship of the bite of the top teeth to the bottom teeth); Left Canine Sagittal relationship: Class I (This describes the relationship of the bite of the top teeth to

the bottom teeth); Maxillary midline in relation to face: Centered (This describes the relationship of the middle of the upper front teeth in relationship to the middle of the face); Mandibular midline in relation to face: Centered (This describes the relationship of the middle of the lower front teeth in relationship to the middle of the face); Maxillary arch length: Crowding, 9 mm (This qualifies and quantifies the discrepancy between the total size of the teeth and the total space available for them in the mouth); Mandibular arch length: Crowding, 3 mm (This qualifies and quantifies the discrepancy between the total size of the teeth and the total space available for them in the mouth).

In this example, the system processes the entries as they are entered, and the doctor is informed to check midlines (right and left sagittal asymmetric, but midlines don't reflect asymmetry). This is because the teeth are being described as one thing, but from three different views. If the system determines that one of the views doesn't match the other two, the doctor is informed. In this way the form checks for intraphase validity. In one condition, the form can inform the doctor that, "Treatment is not recommended for crowding in any arch greater than 6 mm," because 6mm has been decided to be the cutoff point for acceptability.

Once achieving a sound diagnosis, the doctor would then be permitted to enter the treatment goals. In this example, the doctor enters the following as the goals: (1) Right canine sagittal relationship: Class I; (2)Left canine sagittal realtionship : Maintain; and (3) Treat arches: Lower only (In other words, do not do anything with the top teeth).

In this example, the system notifies the doctor that, "The system does not recommended the sagittal changes of the magnitude requested on the right side," because the distance the teeth need to go from the diagnostic position to the goal position of Class

I is too great to be permitted by the appliance. The system would also instruct the doctor that the upper arch needs to be treated to achieve a sagittal change.

Now, assuming legitimate responses have been registered, the start point (diagnosis) and end point (goal) have been established, and the path between the two can be delineated by a list of questions generated in the previous responses. An exemplary treatment plan is (1) Achieve right sagittal change by: Distalize upper molars (A treatment which positions the teeth on the right side to match with the unmoved lower teeth) (2) Relieve maxillary crowding by: Procline incisors; and (3) Relieve mandibular crowding by: Procline incisors.

In one embodiment, the system asks a series of other questions regarding timing of the product delivery, etc. A summary will then be displayed regarding all of the inputs such that the doctor can confirm the entries.

Fig. 9 shows a process 400 associated with a viewer that allows the treating professional to visualize the patient's teeth over the network 102 such as the Internet. In one embodiment, during start-up, a browser checks for a viewer plug-in module embodying the process 400 in a "plug-ins" subdirectory (Windows) or Plug-ins folder (Mac OS) in the same folder or directory as the browser (step 402). If the viewer plug-in module is available, the browser looks for a MIME type and extension info from the version resource. Through a TYPE attribute, the browser knows the MIME type and can load a registered plug-in first and, if there are no matches for the MIME type, the browser looks for a helper application.

Once the viewer plug-in is identified, the browser loads the viewer plug-in code into memory (step 404); initializes the viewer plug-in (step 406); and creates a new

instance of the viewer plug-in (step 408). When the professional leaves the site or closes the window, the viewer plug-in instance is deleted. When the last instance of the viewer plug-in is deleted, the plug-in code is unloaded from memory.

Next, data files are downloaded to the viewer plug-in (step 410). In one implementation, the viewer plug-in downloads a data file from the dental server 102 using a suitable protocol such as a file transfer protocol (FTP). The viewer plug-in uses the downloaded file to present the treatment plan graphically to the clinician. The viewer plug-in also can be used by the treatment plan designer at the host site to view images of a patient's teeth. Fig. 8 shows an exemplary user interface for the viewer plug-in of Fig. 3. The professional can change views, select a particular tooth and change its position as desired (step 412). 3-D images of various orthodontic views can then be rendered after each instruction from the treating professional is received (step 414).

Once the intermediate and final data sets have been created, the appliances may be fabricated as illustrated in FIG. 10. Common fabrication methods employ a rapid prototyping device 501 such as a stereolithography machine. A particularly suitable rapid prototyping machine is Model SLA-250/50 available from 3D System, Valencia, California. The rapid prototyping machine 501 selectively hardens a liquid or other non-hardened resin into a three-dimensional structure that can be separated from the remaining non-hardened resin, washed, and used either directly as the appliance or indirectly as a mold for producing the appliance. The prototyping machine 501 receives the individual digital data sets and produces one structure corresponding to each of the desired appliances. Generally, because the rapid prototyping machine 501 may utilize a resin having non-optimum mechanical properties and which may not be generally

acceptable for patient use, the prototyping machine typically is used to produce molds which are, in effect, positive tooth models of each successive stage of the treatment. After the positive models are prepared, a conventional pressure or vacuum molding machine 551 is used to produce the appliances from a more suitable material, such as 0.03 inch thermal forming dental material, available from Tru-Tain Plastics, Rochester, Minnesota 55902. Suitable pressure molding equipment is available under the trade name BIOSTAR from Great Lakes Orthodontics, Ltd., Tonawanda, New York 14150. The molding machine 551 produces each of the appliances directly from the positive tooth model and the desired material. Suitable vacuum molding machines are available from Raintree Essix, Inc.

After production, the appliances can be supplied to the treating professional all at one time. The appliances are marked in some manner, typically by sequential numbering directly on the appliances or on tags, pouches, or other items which are affixed to or which enclose each appliance, to indicate their order of use. Optionally, written instructions may accompany the system which set forth that the patient is to wear the individual appliances in the order marked on the appliances or elsewhere in the packaging. Use of the appliances in such a manner will reposition the patient's teeth progressively toward the final tooth arrangement.

Because a patient's teeth may respond differently than originally expected, the treating clinician may wish to evaluate the patient's progress during the course of treatment. The system can also do this automatically, starting from the newly-measured in-course dentition. If the patient's teeth do not progress as planned, the clinician can revise the treatment plan as necessary to bring the patient's treatment back on course or

to design an alternative treatment plan. The clinician may provide comments, oral or written, for use in revising the treatment plan. The clinician also can form another set of plaster castings of the patient's teeth for digital imaging and manipulation. The clinician may wish to limit initial aligner production to only a few aligners, delaying production on subsequent aligners until the patient's progress has been evaluated.

FIG. 11 is a simplified block diagram of a data processing system 600 that may be used to develop orthodontic treatment plans. The data processing system 600 typically includes at least one processor 602 that communicates with a number of peripheral devices via bus subsystem 604. These peripheral devices typically include a storage subsystem 606 (memory subsystem 608 and file storage subsystem 614), a set of user interface input and output devices 618, and an interface to outside networks 616, including the public switched telephone network. This interface is shown schematically as "Modems and Network Interface" block 616, and is coupled to corresponding interface devices in other data processing systems via communication network interface 624. Data processing system 600 could be a terminal or a low-end personal computer or a high-end personal computer, workstation or mainframe.

The user interface input devices typically include a keyboard and may further include a pointing device and a scanner. The pointing device may be an indirect pointing device such as a mouse, trackball, touchpad, or graphics tablet, or a direct pointing device such as a touchscreen incorporated into the display, or a three dimensional pointing device, such as the gyroscopic pointing device described in U.S. Patent 5,440,326, other types of user interface input devices, such as voice recognition systems, can also be used.

User interface output devices typically include a printer and a display subsystem, which includes a display controller and a display device coupled to the controller. The display device may be a cathode ray tube (CRT), a flat-panel device such as a liquid crystal display (LCD), or a projection device. The display subsystem may also provide non-visual display such as audio output.

Storage subsystem 606 maintains the basic required programming and data constructs. The program modules discussed above are typically stored in storage subsystem 606. Storage subsystem 606 typically comprises memory subsystem 308 and file storage subsystem 614.

Memory subsystem 608 typically includes a number of memories including a main random access memory (RAM) 610 for storage of instructions and data during program execution and a read only memory (ROM) 612 in which fixed instructions are stored. In the case of Macintosh-compatible personal computers the ROM would include portions of the operating system; in the case of IBM-compatible personal computers, this would include the BIOS (basic input/output system).

File storage subsystem 614 provides persistent (non-volatile) storage for program and data files, and typically includes at least one hard disk drive and at least one floppy disk drive (with associated removable media). There may also be other devices such as a CD-ROM drive and optical drives (all with their associated removable media). Additionally, the system may include drives of the type with removable media cartridges. The removable media cartridges may, for example be hard disk cartridges, such as those marketed by Syquest and others, and flexible disk cartridges, such as those marketed by

Iomega. One or more of the drives may be located at a remote location, such as in a server on a local area network or at a site on the Internet's World Wide Web.

In this context, the term "bus subsystem" is used generically so as to include any mechanism for letting the various components and subsystems communicate with each other as intended. With the exception of the input devices and the display, the other components need not be at the same physical location. Thus, for example, portions of the file storage system could be connected via various local-area or wide-area network media, including telephone lines. Similarly, the input devices and display need not be at the same location as the processor, although it is anticipated that personal computers and workstations typically will be used.

Bus subsystem 604 is shown schematically as a single bus, but a typical system has a number of buses such as a local bus and one or more expansion buses (e.g., ADB, SCSI, ISA, EISA, MCA, NuBus, or PCI), as well as serial and parallel ports. Network connections are usually established through a device such as a network adapter on one of these expansion buses or a modem on a serial port. The client computer may be a desktop system or a portable system.

Scanner 620 is responsible for scanning casts of the patient's teeth obtained either from the patient or from an orthodontist and providing the scanned digital data set information to data processing system 600 for further processing. In a distributed environment, scanner 620 may be located at a remote location and communicate scanned digital data set information to data processing system 600 via network interface 624. Fabrication machine 622 fabricates dental appliances based on intermediate and final data set information received from data processing system 600. In a distributed environment,

fabrication machine 622 may be located at a remote location and receive data set information from data processing system 600 via network interface 624.

The invention has been described in terms of particular embodiments. Other embodiments are within the scope of the following claims. For example, the three-dimensional scanning techniques described above may be used to analyze material characteristics, such as shrinkage and expansion, of the materials that form the tooth castings and the aligners. Also, the 3D tooth models and the graphical interface described above may be used to assist clinicians that treat patients with conventional braces or other conventional orthodontic appliances, in which case the constraints applied to tooth movement would be modified accordingly.